NASA's Evolvable Cryogenics (eCryo) Project

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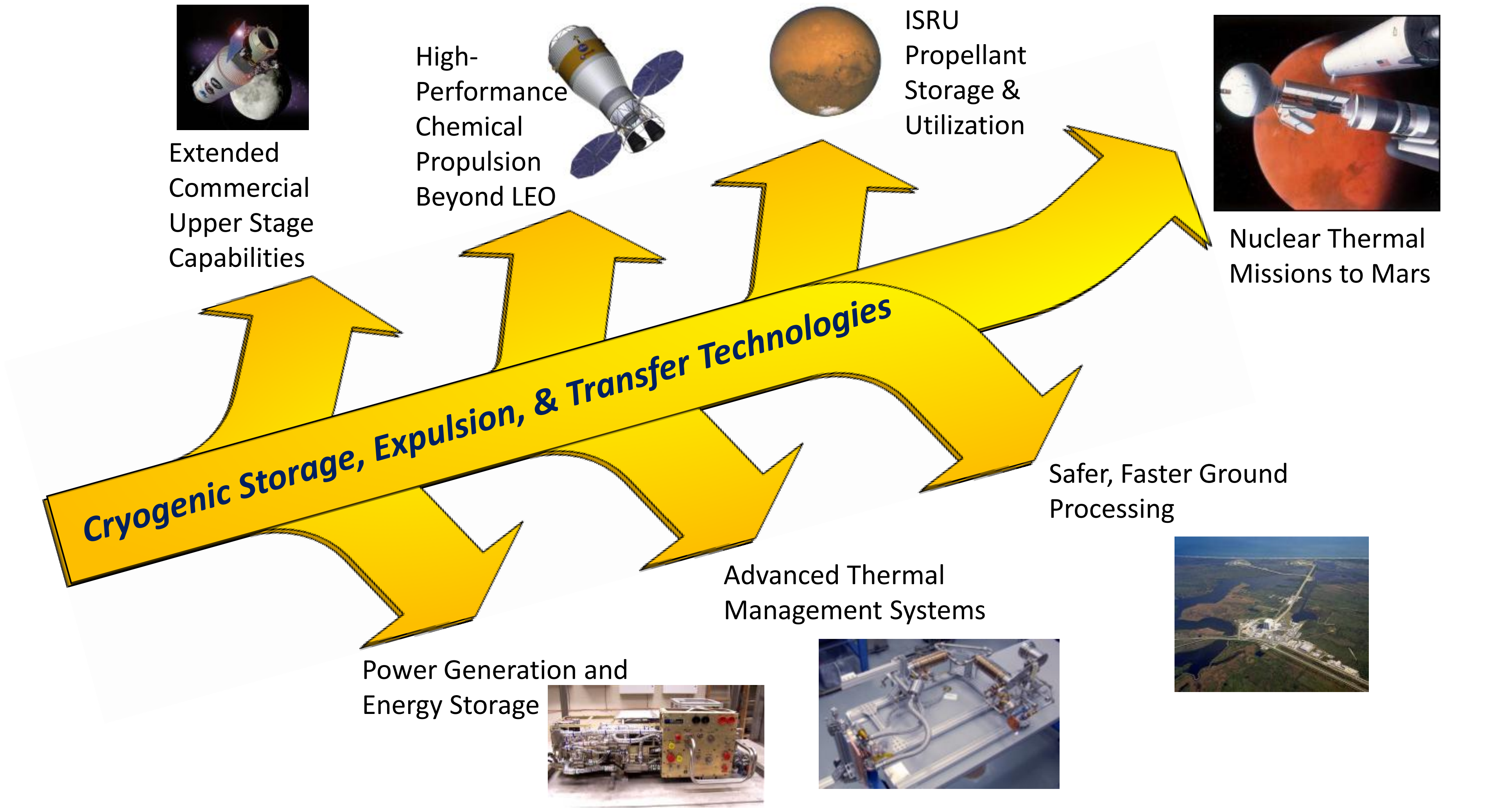
Cryogenic Propellant Technology Cross-Cutting Benefits



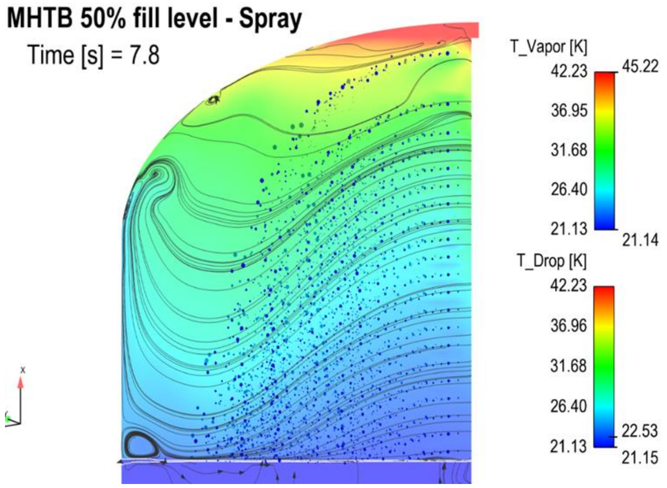
CFM Development Mitigates Risks for Multiple Architecture Elements and Systems

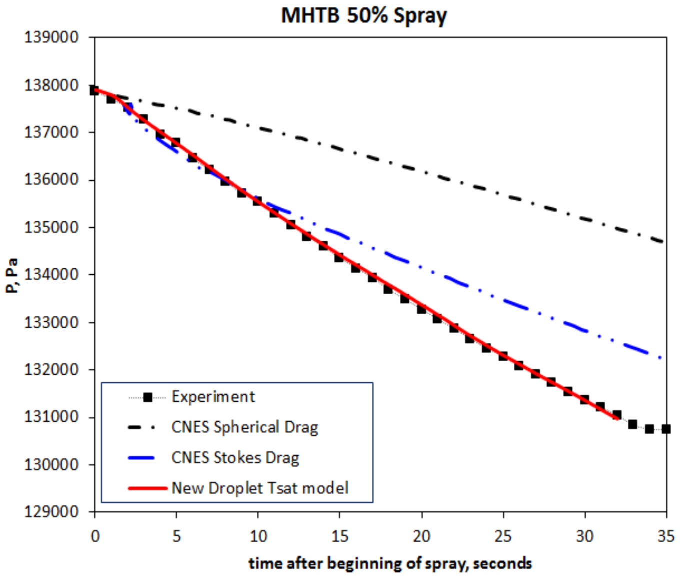
eCryo Overview

- eCryo is working to enable cryogenic fluid management technologies for large applications
  - Upper stages
  - Depots
  - Landers
- Four key areas
  - Development and validation of computational modeling and analysis tools
  - Multilayer insulation for large cryogenic applications
  - Vapor based heat intercept
  - Radio Frequency Mass Gauging
- Environmental considerations
  - Large scale, ground based
  - Small scale, flight based (using simulant fluids)

Development and Validation of Analysis Tools

- Extension of multinode codes:
  - To three dimensions
  - To unsettled (microgravity) conditions
  - Multiple codes
    - Generalized Fluid System Simulation Program (GFSSP)
    - SINDA/FLUINT
  - Goal of modeling pressure control in unsettled conditions
- Incorporated improved drop spray model into FLUENT
  - Improved correlations over previous results from collaboration with CNES
  - Resolved major issues with mixing of ullage and pressure control

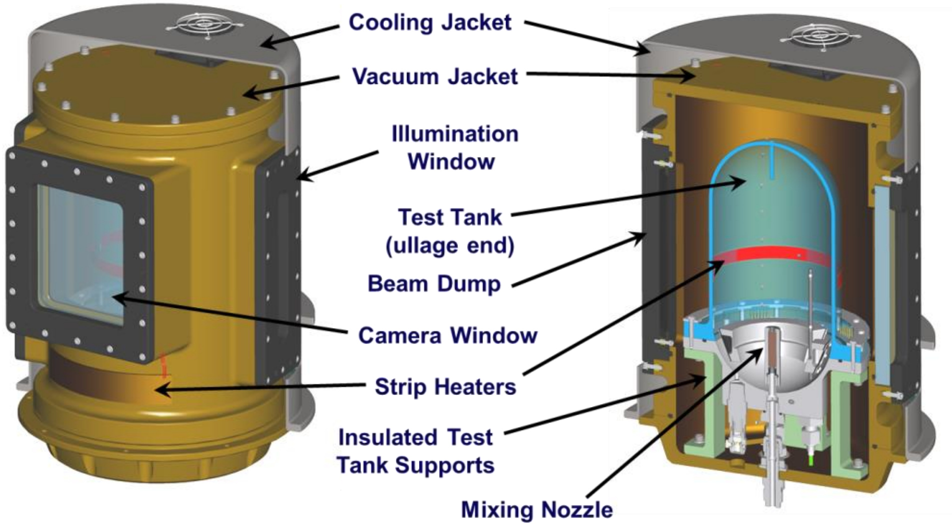


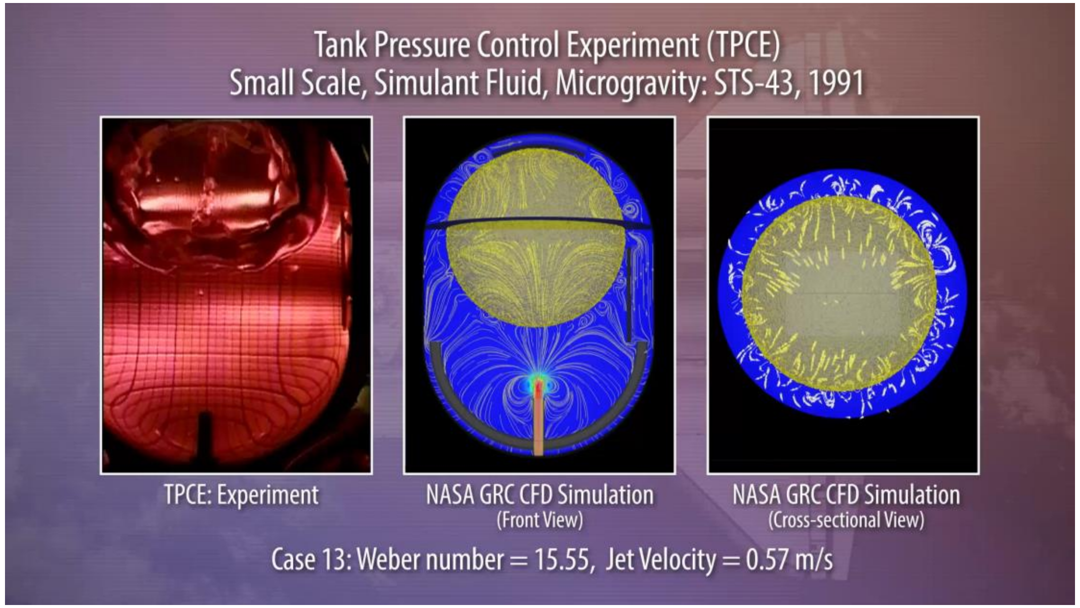


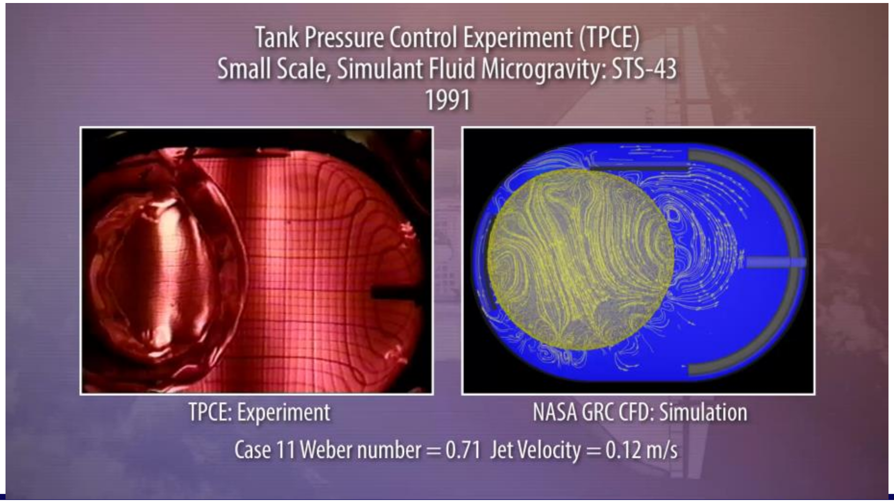
Development and Validation of Analysis Tools

- Validation of Computational Fluid Dynamic models with microgravity data
  - TCPE (1991, 1993)
  - RRM3 (Launch 2017 - TBR)
  - ZBOT (Launch 2016)

ZBOT

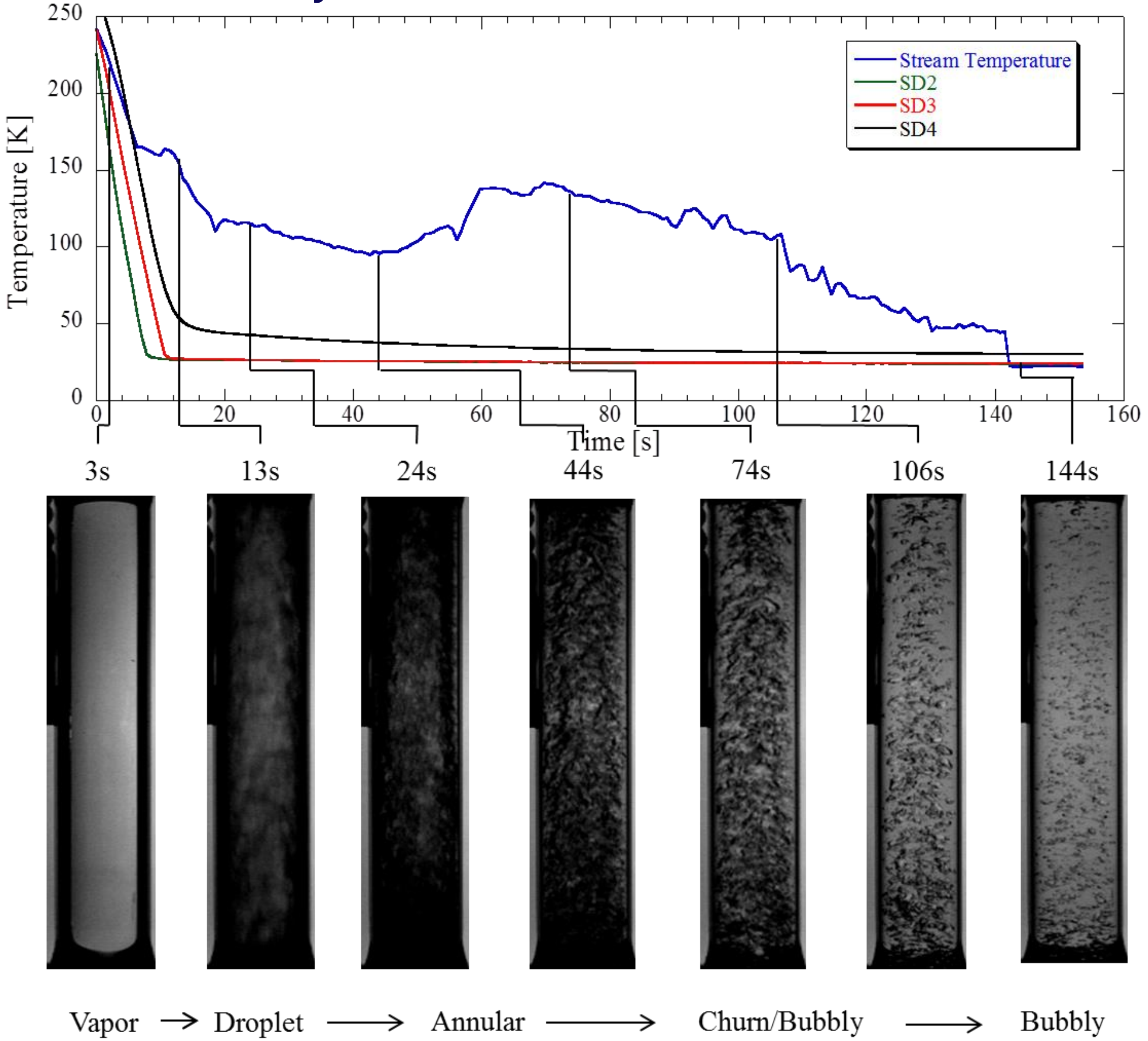






Development and Validation of Analysis Tools

- Improving modeling of line and tank childown
- Develop a “universal heat transfer correlation” that addresses heat transfer during chilldown using cryogenic fluids
  - Liquid hydrogen data
  - Liquid nitrogen data
- Integrating correlation into multi-node based codes

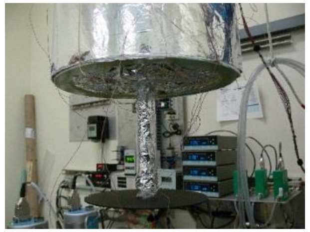


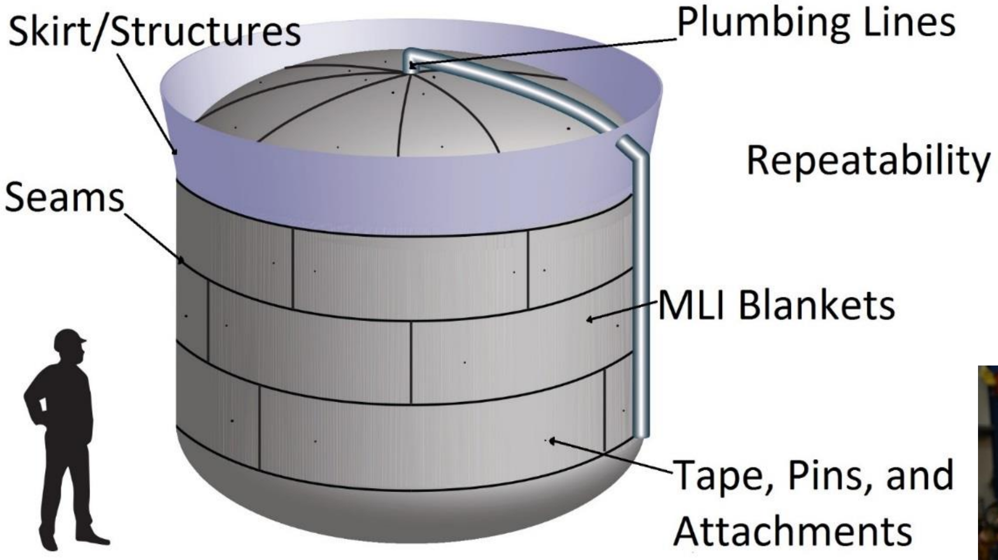
Multilayer Insulation

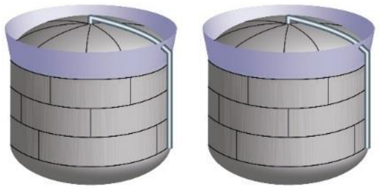
- Adding insulation is the first step to take to reduce the heat load into any system
- Spacecraft use multilayer insulation (MLI) for the radiative environments that are in space
- Most spacecraft are small, most upper stages are large
- Extend Multilayer Insulation to large cryogenic applications

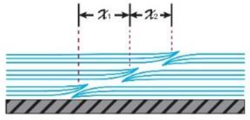
Basic material properties only tell the first chapter of the story…

…the rest is told by how you install the MLI as a system.

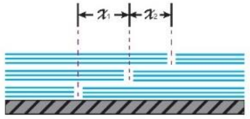








3 Blanket Overlap Staggered



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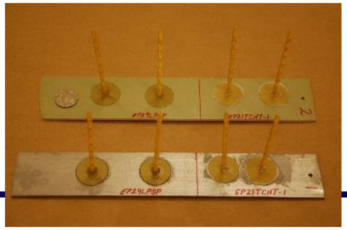
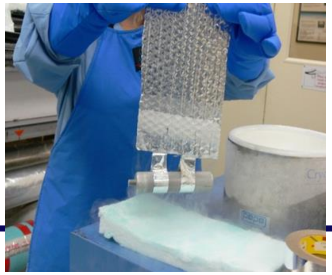
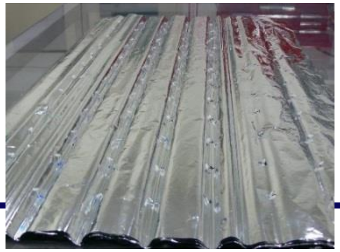
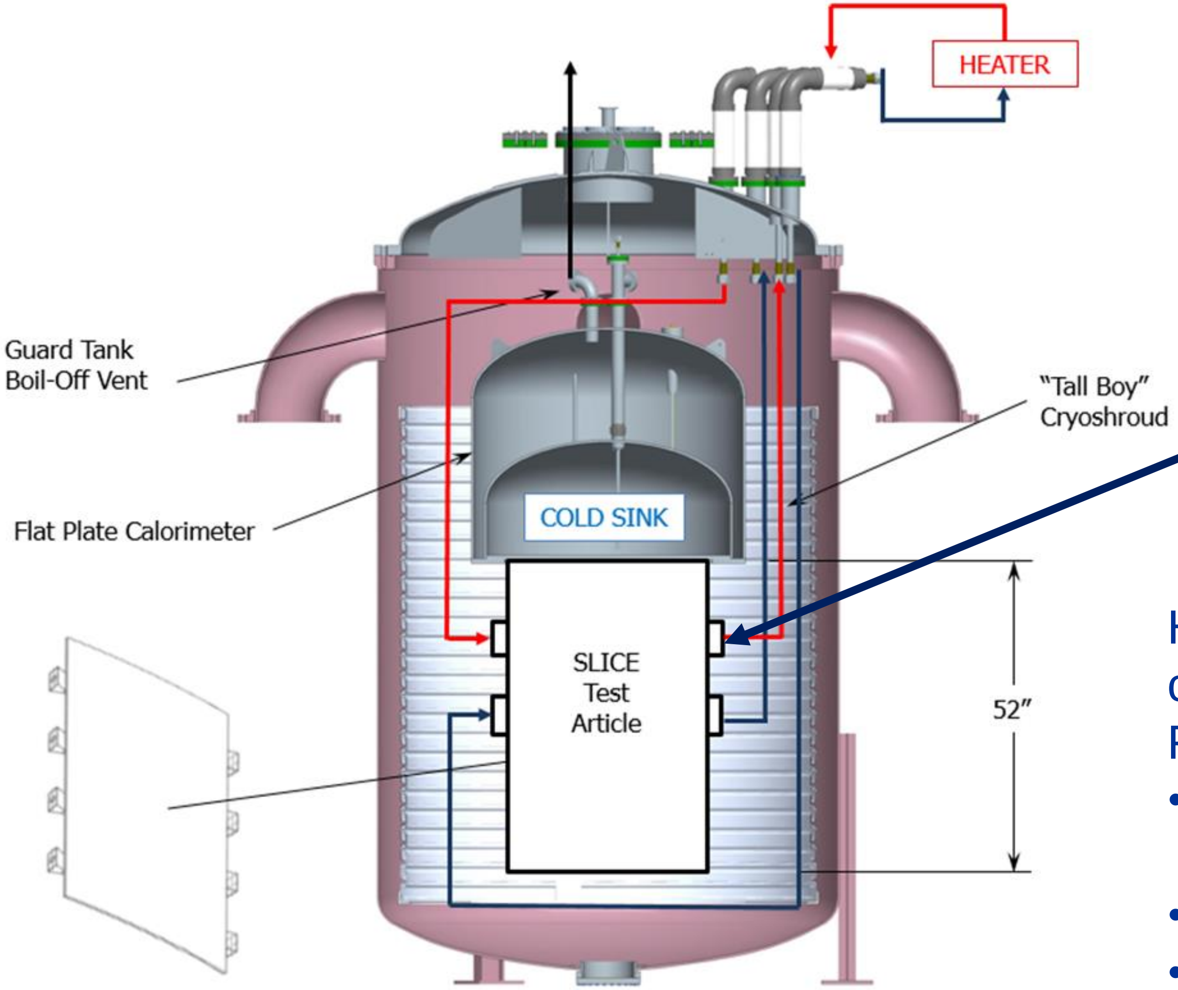


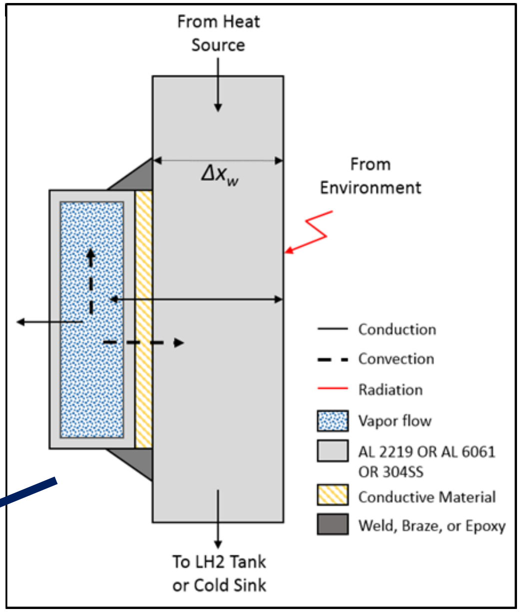




Vapor Based Heat Intercept

- Heat going into an upper stage generates “boil-off”, or vapor that must be vented
- The vapor is generally cold (below 100 K)
- Why not use the cold vapor to reduce the heat coming into the tank?
- Getting the heat out of the skirt efficiently is not easy!



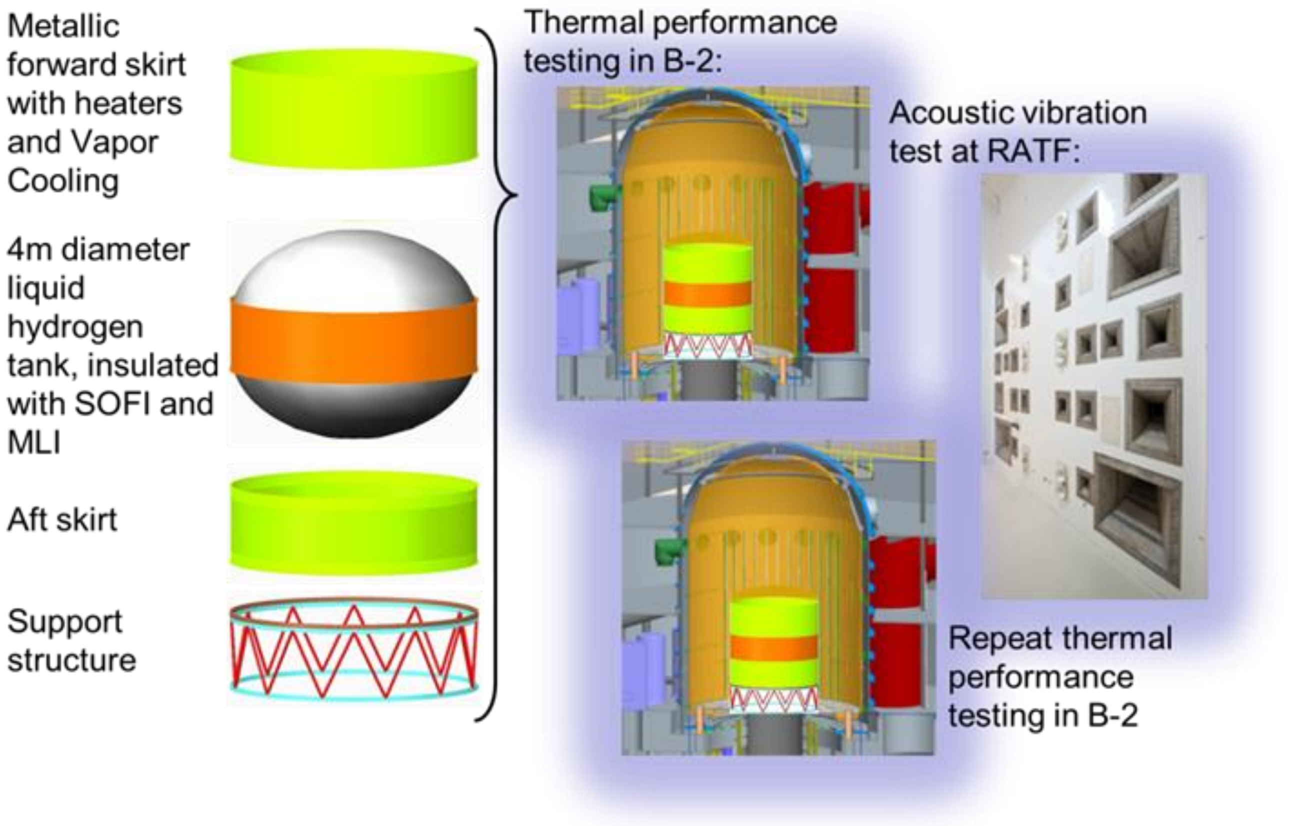


How efficient can vapor cooling be?
Function of:

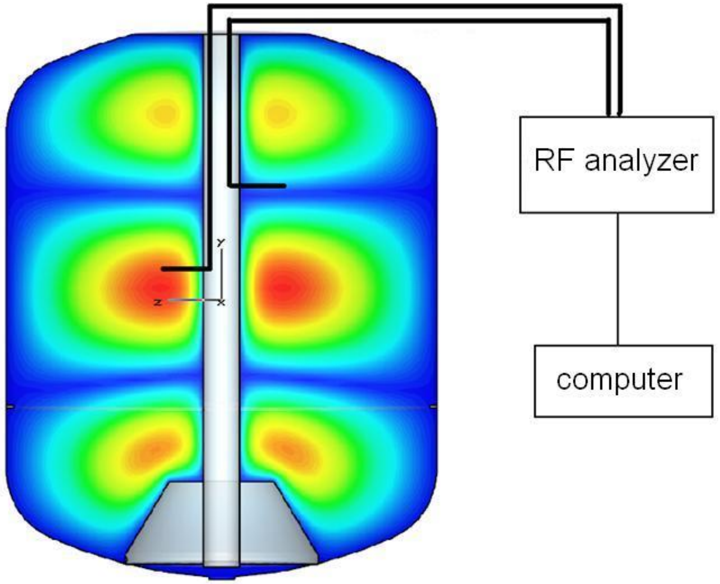
- Temperature (fluid relative to article)
- Thermal resistance
- Mass flow
- Configuration
- Tank fill level

Large Scale Implementation

- Evaluate MLI and vapor based heat intercept on a 4 m (quasi-full stage) tank
- Establish a baseline for understanding system performance:
  - No flow in vapor flow network
  - Spray on Foam Insulation
- Install MLI on domes only
  - Inside protective shrouds of launch vehicle
  - NASA has no “ready” technologies for outside of a launch vehicle shroud during ascent
  - Install removable MLI on outer surface to demonstrate potential gains by developing insulation that can survive launch
- Operate vapor fluid flow network
  - At different tank fill levels
  - At different flow rates/bypass rates
- Expose MLI to reverberant acoustic environment and then retest thermal
  - Look for degradation of performance



Radio Frequency Mass Gauge



- Metal tank has natural RF modes

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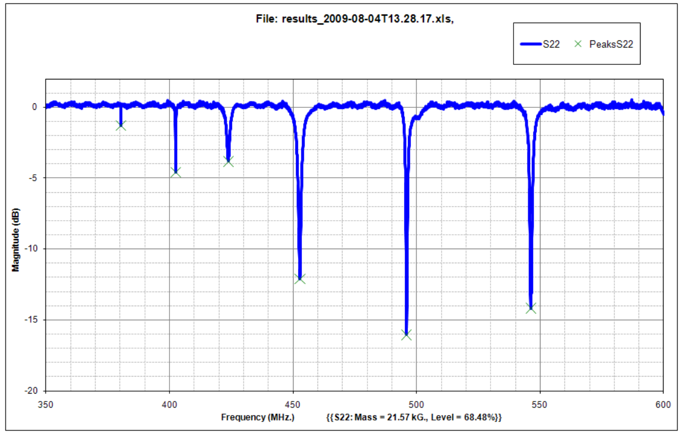
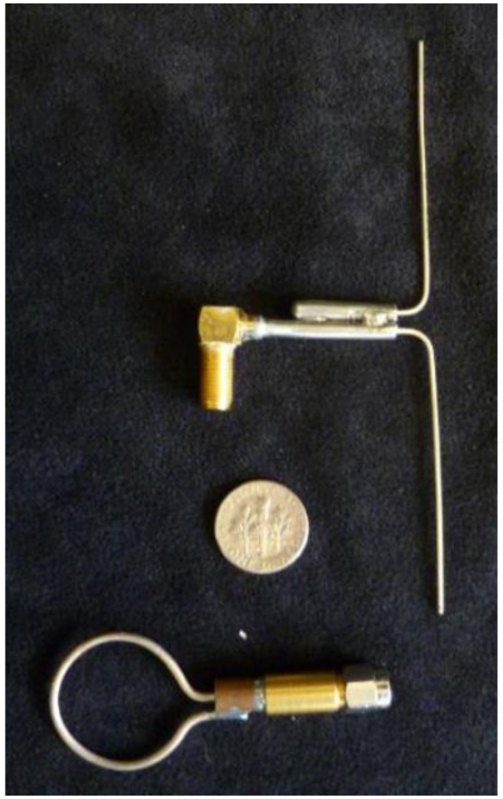
- RF network analyzer measures the tank spectrum



- The tank RF spectrum changes with fill level, since the dielectric fluid slows the speed of light

- The basis of the RFMG is that these changes can be accurately predicted

- RFMG software finds the peaks, compares the frequencies to a database of simulations, and returns the best match %fill-level information



Summary

- Cryogenic based propulsion can open the exploration of:
  - Cis-lunar space
  - The inner planets (manned)
  - The outer planets (un-manned)
- eCryo is pushing to evolve technologies for the next generation of exploration
  - Improved performance of cryogenic upper stages
  - Improved performance of landers (both moon and Mars)
  - Enabling performance for in-space cryogenic depots
- Further technology development that ends up in a flight demonstration is the next step forward in enabling the long duration storage and transfer of cryogenic propellants in microgravity